Algal productivity in the Patuxent is high relative to that in other estuaries (Boynton et al., 1982). Bloom conditions (> 60-100 µg/liter chlorophyll a) are frequently found in tidal freshwater habitats (O'Connor et al., 1981). Anthropogenic nutrient inputs from point sources (sewage treatment facilities) and non-point sources (agricultural lands) are the major factors contributing to this high productivity (O'Connor et al., 1981). Most (50-80%) of the carbon produced by phytoplankton in the Patuxent settles to the bottom in the Patuxent as particulate carbon detritus, which is used by the benthos or permanently buried (Boynton et al., 1982; O'Connor et al., 1981).

Spatial (longitudinal) changes in phytoplankton biomass and productivity in the Patuxent River are largest and most rapid in the Chalk Point region (Flemer et al., 1970; Herman et al., 1968; Stross and Stottlemeyer, 1965; ANSP, 1983a). These changes are related to natural longitudinal gradients in salinity and nutrient concentrations (refer to Chapter II - The Physical and Chemical Environment for details). Quantification of power plant effects to phytoplankton thus is difficult; it depends on the accuracy with which changes in phytoplankton populations can be attributed to these natural gradients vs power plant operations.

Seasonal variation in phytoplankton productivity and biomass is large in all salinity zones of the Patuxent River. Both biomass (chlorophyll a concentration) and primary production peak in late spring and summer and decline to low levels in winter (Flemer et al., 1970; Herman et al., 1968; Stross and Stottlemeyer, 1965; ANSP, 1983a). Phytoplankton productivity and biomass levels decrease in fall and increase in spring. The spring increase in phytoplankton productivity and biomass coincides with a period of high concentrations of dissolved nutrients, which are brought in with freshwater inflows (Flemer et al., 1970; Herman et al., 1968; Stross and Stottlemeyer, 1965; ANSP, 1983a; D'Elia and Boynton, 1982). The summer productivity and biomass peak, however, occurs when dissolved nutrient stocks in the water column are low. Ammonia flux from the sediments is thought to be the primary process controlling summer nutrient availability and thus phytoplankton productivity and biomass (Boynton et al., 1982), although the availability of light during summer is also an important factor (D'Elia and Boynton, 1982). In the turbid tidal freshwater and oligohaline habitats, summer light levels frequently limit phytoplankton productivity to depths not more than 10-20 cm below the water surface. As a result, areal phytoplankton production is greater in the more saline, less turbid areas below the Benedict Bridge than in the less saline areas above it (Flemer et al., 1970; ANSP, 1983).

The large year-to-year variation in phytoplankton productivity and biomass is due to a number of factors, including long-term trends and year-to-year variation in anthropogenic inputs, particularly of inorganic nutrients; year-to-year variation in certain climatic factors, particularly rainfall; and natural long-term biological cycles (Flemer et al., 1970; Herman et al., 1968; Stross and Stottlemeyer, 1965; Mihursky and Boynton, 1978; ANSP, 1983a; D'Elia and Boynton, 1982).

During partial-power plant operations, phytoplankton biomass (chlorophyll a concentration) generally declined during entrainment; on 13 of 16 dates covering all seasons, chlorophyll a concentration was higher in the intake area than at the head of the discharge canal (ANSP, 1983a). These reductions averaged about 20%. However, because there was no apparent relationship between ΔT, ambient temperature, chlorination, and cross-condenser declines in phytoplankton biomass, a large part of the cross-condenser declines appears to be due to mechanical damage. In summer and early fall, entrainment during partial-power operations depressed phytoplankton productivity when chlorine was applied (Morgan, 1969; Morgan et al., 1969; Morgan and Stross, 1969; Hamilton et al., 1970; Flemer and Sherk, 1977; ANSP, 1983a). Without chlorine application, entrainment at partial loads frequently enhanced phytoplankton productivity, but this enhancement was inconsistent (Morgan et al., 1969; Hamilton et al., 1970; ANSP, 1983a). Power plant effects on phytoplankton thus include thermal effects (positive and negative), chemical effects (negative), and mechanical damage (negative).

Entrainment-related losses and gains in phytoplankton did not have consistent nearfield effects on algal productivity or biomass (Flemer et al., 1970; ANSP, 1983a). Also, power plant operations did not change phytoplankton species composition in the nearfield (ANSP, 1983a).

The effects of auxiliary pump operations on phytoplankton have not been quantified, but probably are not as great as those of through-plant entrainment, discussed above. Mechanical damage appears to be a major source of through-plant mortality in phytoplankton and is likely to be a major source of auxiliary-pump-entrainment mortality as well. Discharge canal chlorine levels are also stressful to Patuxent phytoplankton populations (ANSP, 1983a). Because the general stress levels from auxiliary pump entrainment are less than those associated with through-plant entrainment, the recovery and reproduction of phytoplankton after auxiliary pump entrainment should thus be more rapid than their recovery and reproduction after through-plant entrainment (ANSP, 1983a). Because phytoplankton mortality in the discharge canal is low, even during midsummer chlorination, the benefit decreases in discharge canal temperatures from auxiliary pumping to these organisms is questionable.

The stem count and biomass of widgeon grass and the stem count of redhead grass decreased, whereas the biomass of redhead grass increased, at thermally affected stations (Anderson, 1966; Anderson et al., 1968; Anderson and Rappleye, 1969; ANSP, 1983a). Low concentrations of chlorine (0.1-0.5 ppm) had no detrimental effects on Eastern milfoil (Myriophyllum pinnatum) and southern wild rice (Zizania aquatica) (ANSP, 1981, 1983a). Unfortunately, the extensive beds of submerged macrophytes that were present near the Chalk Point SES in 1964 were absent in 1974 (ANSP, 1983a). These declines, however, were probably not due to power plant operations; similar declines throughout the Chesapeake Bay have been attributed to decreases in available light that resulted from increases in suspended sediment loadings and phytoplankton productivity (U.S. EPA, 1983; Bayley et al., 1978). The emergent marsh plants inhabiting the effluent canal (Spartina alterniflora and Phragmites australis) have been exposed to plant effluents with temperatures as high as 39-40°C for the last 30 years without detectable detrimental effects (Anderson et al., 1968; ANSP, 1983a).

D. SIGNIFICANCE OF FINDINGS AND CONCLUSIONS

The findings presented above indicate that the Chalk Point SES affects the "biological productivity" of Patuxent phytoplankton populations. However, the effects are generally limited to the discharge canal and immediate discharge region (i.e., they do not extend outside of the allowable mixing zone). Partial power generation does not increase the abundance or distribution of nuisance plants such as blue-green algae, and full power generation also is not likely to create an environment favoring blue-green algae (ANSP, 1983a).

The major factors affecting phytoplankton productivity and biomass at Chalk Point are nutrient loading from point and nonpoint sources and nutrient regeneration from the sediments. Operations of the Chalk Point SES is relatively unimportant in determining phytoplankton productivity and biomass, even in the immediate vicinity of plant discharges. Although entrainment results in large phytoplankton mortalities, the surviving population usually recovers and begins to reproduce before reaching the terminus of the discharge canal, so consistent nearfield depletions of phytoplankton have not been observed. The major adverse influence of the Chalk Point SES on phytoplankton productivity and biomass is entrainment mortality associated with chlorine toxicity and mechanical damage. This mortality is not likely to increase during full power generation, because chlorine use and plant pumping rate are similar during partial and full power generation. Although full load operations will enlarge the nearfield zone of power plant influence, no regional effects on phytoplankton are expected. Patuxent phytoplankton populations recover rapidly (in hours) from entrainment effects.

Management plans for the Patuxent estuary (U.S. EPA, 1983) include large reductions in nutrient loadings. Although such actions will reduce phytoplankton biomass and productivity in the Chalk Point region, they are not likely to change the direction or relative magnitude of power plant effects on phytoplankton communities. Operations of the Chalk Point SES affect phytoplankton mainly through entrainment mortality. Recovery from entrainment is rapid because of the elevated temperatures of plant effluents in combination with the rapid growth rates of phytoplankton. However, if SAV beds occurred in the immediate discharge area of the Chalk Point SES (i.e., the allowable mixing zone defined by paragraph E(1)(d) in COMAR 10.50.01.13), they would be adversely affected by power plant operations.

The use of auxiliary pumps increases entrainment losses of phytoplankton, but neither increases nor decreases the magnitude of nearfield effects to them. Dilution of thermal effluents by auxiliary pumps is thus of little benefit to phytoplankton populations, because thermal effects in the discharge canal are not the major source of phytoplankton mortality. Auxiliary pumping actually increases the risk of phytoplankton mortality due to mechanical damage and exposure to chlorine and their discontinuance would enhance these populations.

IV. ZOOPLANKTON

A. INTRODUCTION

Zooplankton are primary grazers on phytoplankton and constitute an important food source for organisms at higher trophic levels, particularly early life stages of RIS fish such as striped bass and white perch (Westin and Rogers, 1978; Raney, 1952; Beaven and Mihursky, 1980; Mansueti, 1964). Environmental perturbations, either natural or anthropogenic, that modify zooplankton distributions can, therefore, alter food web relationships and indirectly affect fishery stocks.

Because they are weak swimmers, zooplankton are distributed longitudinally by currents. They can, however, and frequently do, move vertically in the water in response to diel variations in light. Surface densities of many zooplankton are highest at night, and bottom densities are highest during the day (Lippson et al., 1979). Salinity is the major factor controlling riverwide zooplankton distributions. Factors influencing their seasonal distributions include temperature, predation, and competition (Lippson et al., 1979). Predation is particularly important in summer when large numbers of ctenophores, a major predator, frequently crop dominant estuarine zooplankton to very low levels (Bishop, 1967).

B. TYPES OF POWER PLANT IMPACTS

The major adverse effects of the Chalk Point SES on zooplankton are physiological injury and direct mortality from entrainment into cooling water flows. Several studies have shown that the magnitude of zooplankton entrainment mortality is directly proportional to the duration of exposure to elevated temperature (Reeve and Casper, 1970; Schubel and Marcy, 1978). At Chalk Point, the duration of exposure to temperature higher than ambient is relatively long because plant effluents are routed through a 2-km discharge canal. Entrained zooplankton are mechanically injured from abrasion, velocity shear, and pressure changes during passage through the condenser cooling system (Schubel and Marcy, 1978). In addition, during warm weather, they are exposed to acutely lethal concentrations of chlorine and its residuals.

Zooplankton that survive entrainment may display comatose behavior from heat shock (Goss and Bunting, 1976; Bradley, 1975);

this behavior makes them more vulnerable to predation when returned to the receiving waters. Entrainment may also strip undeveloped eggs from gravid female copepods, thereby decreasing the reproductive potential of the population.

Cooling water at Chalk Point is discharged 2 km upstream of the intake, so the weakly swimming zooplankton can be reentrained. With all pumps operating, the reentrainment rate is as high as 4% per day during periods of low freshwater inflow (Binkerd et al., 1980) and about 1% per day during periods of average freshwater inflow (Edinger and Buchack, 1984).

During warm periods, auxiliary pumps withdraw zooplankton from the intake region, pump them into the discharge canal, where they are exposed to near-lethal temperatures and chlorine concentrations. These exposures result in injury as well as direct mortality. Passage through auxiliary pumps also causes mechanical damage to zooplankton. Auxiliary pump operations thus increase the number of zooplankton at risk to plant effluents.

Power plant discharges also affect the abundance and distribution of zooplankton in the receiving waters by exposing nearfield populations to thermal effluents and any associated chemical toxicants. Plume entrainment can cause direct mormortality or modify the behavior and physiology of nearfield zooplankton populations. Losses due to plume entrainment are generally smaller than losses due to condenser cooling-water entrainment (Martin Marietta Corporation, 1980).

C. SUMMARY OF SPECIFIC FINDINGS

Zooplankton are particularly abundant in the Chalk Point region. Both estuarine and, to a lesser extent, freshwater species inhabit the area (Herman et al., 1968; Heinle, 1966; ANSP, 1983a, Sellner and Horwitz, 1983). The most abundant zooplankton are the calanoid copepods *Acartia tonsa* and *Eurytemora affinis*. *Eurytemora affinis* is dominant in late fall to early spring, whereas *A. tonsa* generally dominates zooplankton assemblages from late spring to early fall. Also commonly found, but usually much less abundant than the calanoid copepods are zooplankton of other groups, such as harpacticoid and cyclopoid copepods, cladocerans, barnacle and polychaete larvae, and rotifers. (Herman et al., 1968; Heinle, 1966; ANSP, 1983a, Sellner and Horwitz, 1983). Rotifers have generally been undersampled by studies conducted at Chalk Point, because the mesh sizes of the sampling nets used have been too large.

Zooplankton densities throughout much of the Patuxent are often low in summer, a time when, according to known growth and reproductive patterns, densities should be high. These low abundance periods correspond to periods of high ctenophore abundance. Ctenophores are very efficient predators on zooplankton and can reduce zooplankton standing crops to very low levels (Herman et al., 1968; Heinle, 1966; ANSP, 1983a; Bishop, 1967).

Laboratory studies on the thermal tolerances of _A. tonsa_ and _E. affinis_ indicate that their upper tolerance limits are near the ambient summer temperatures at Chalk Point. For _A. tonsa_ acclimated at 20 or 25°C, the upper thermal tolerance limit was 30-35°C. _E. affinis_ acclimated at 25°C died when exposed to 30°C (Heinle, 1969). Thus, in summer, Chalk Point discharge canal temperatures are in ranges lethal for zooplankton during partial-power operations; nearfield temperatures may approach lethal levels during full-power operation.

The complex effects of entrainment on zooplankton populations are best presented by an overview of the entrainment data. During partial-power operations, zooplankton losses from entrainment generally were largest during periods of chlorination, when reductions in zooplankton density from intake to the end of the discharge canal frequently were 30-80% (ANSP, 1983a; Heinle, 1976). Chlorination was sometimes, however, followed by little or no entrainment loss of zooplankton. Without chlorination, through-plant losses averaged 20-30%, but frequently were zero, particularly during colder seasons (Heinle, 1976; ANSP, 1983a). Entrainment-related declines in abundance of zooplankton were most apparent when overall densities were relatively high (ANSP, 1983a). Population abundance frequently was further reduced as zooplankton passed down the discharge canal, especially when chlorine was used (ANSP, 1983a). Harpacticoid copepods were more tolerant of entrainment stresses than calanoid copepods (Heinle, 1976; ANSP, 1983a). Much of the observed variation in zooplankton entrainment losses is associated with sampling problems (ANSP, 1983a). Zooplankton distributions in the intake frequently were stratified with respect to depth and time of day, whereas distributions in the discharge canal were well mixed (Heinle, 1976, ANSP, 1983a). Despite entrainment sampling problems and the resulting large variation in loss estimates, entrainment was a major source of zooplankton mortality, especially during periods of chlorination.

Full-power generation is expected to result in entrainment mortality rates of 90-100% during summer, when temperatures in the discharge canal are projected to exceed 35°C substantially more than 18% of the time (summer discharge temperatures exceeded 35°C at least 18% of the time from 1981 to 1983, when the plant was operating at about 50% of full generating capacity -- PEPCO, unpublished data). Full power operation is not projected to result in increases in entrainment mortality during winter, spring, and fall because during these seasons, discharge temperatures will not be lethal to most zooplankton populations.

Other major plant-related sources of zooplankton mortality do not change between partial- and full-power generating levels.

Densities of zooplankton entrained in the auxiliary pumping system usually paralleled densities entrained in the cooling system, but there were no obvious losses of zooplankton immediately after passage through the auxiliary pumps. Thus, entrainment in the auxiliary pumping system did not appear to cause mechanical damage. The discharge-canal mortality rate for zooplankton entrained through the auxiliary pumps was not specifically measured but is not likely to exceed 10% as long as discharge canal temperatures are less than 35°C and chlorine (TRC) levels are less than 0.20 ppm (ANSP, 1983a). As discussed above, however, even with auxilliary pumps operating discharge canal temperatures at full power are projected to exceed 35°C for much of the summer (PEPCO, unpublished data). During this period, auxiliary pump entrainment will probably result in zooplankton mortality rates approaching 100%.

During summertime partial-power operations, zooplankton densities in the nearfield were occasionally lower than at reference locations (ANSP, 1983a). The size of the reduction varied (15-40%) and was not consistently related to ΔT. Chlorine use appeared to be the most important factor in these losses -- not a surprising finding since the highest and most consistent zooplankton entrainment losses were associated with chlorine use. At full-power generation, nearfield effects on zooplankton will be more frequent and should extend over more of the immediate discharge area. Full-power depletions of zooplankton, however, are not likely to be regional in scope.

D. SIGNIFICANCE OF FINDINGS AND CONCLUSIONS

When operating at either full or partial load, the Chalk Point SES reduces the "biological productivity" of the Patuxent zooplankton populations. During partial-power operations, zooplankton abundance was reduced over a limited area of the immediate discharge region during warm seasons. These depletions were attributable to entrainment losses, with most of the losses resulting from the synergistic effects of high ambient temperature, large change in temperature, and chlorine toxicity. During full-power operation, projected discharge-canal and nearfield temperatures would be high enough to cause direct mortality of zooplankton, and the frequency and magnitude of depletions in nearfield populations are expected to increase substantially. The area over which nearfield depletions occur may also increase. Full-power effects are not projected to be regional, however, but should be limited to the Chalk Point vicinity.

Even though entrainment losses through auxiliary pumps are small, 1/3 more zooplankton are exposed to the stressful discharge-canal environment when these pumps are used than when they are not. In theory, the use of auxiliary pumps should reduce absolute temperatures in the Chalk Point discharge canal below the lethal limits for zooplankton during extreme summer conditions, but recent data (PEPCO, unpublished data) indicate otherwise; at partial-power generation loads and with auxiliary pumps operating, discharge canal temperatures exceeded the lethal limit for dominant Patuxent zooplankton 18% of the time during summer (39% of the time during July). Thus, auxiliary pumps do not reduce zooplankton entrainment mortality, and their continued use should be carefully evaluated.

V. BENTHIC INVERTEBRATES

A. INTRODUCTION

Bottom sediments and the surfaces of submerged objects (e.g., shells and SAV) are habitats for many species of organisms, known collectively as benthic invertebrates. Crabs, clams, and oysters are some of the larger and more familiar benthic organisms harvested commercially in Maryland. The dominant benthic fauna inhabiting the Chalk Point region, however, are mostly smaller organisms (e.g., crustaceans, worms, and clams) that are not harvested commercially. The kinds and relative abundances of benthic macroinvertebrates in estuaries are determined by environmental conditions (Rhoads, 1974; Lippson et al., 1979). Salinity is the primary factor determining regional distributions, and sediment properties are the primary factors determining local distributions (Boesch, 1977; Mountford et al., 1977).

Benthic organisms have a variety of functions within estuarine ecosystems. They convert organic substances into biomass, which subsequently serves as food for fish and crabs (Lippson et al., 1979; Holland et al., 1980). In addition, burrowing and feeding by benthic organisms accelerate the rate at which nutrients bound in sediments are returned to the water column (Boynton et al., 1982; Callender and Hammond, 1982). Nutrients recycled from bottom sediments constitute a major part of the nutrient stocks available for primary producers in summer (Boynton et al., 1982).

Adult benthic organisms are generally sessile, and thus cannot escape environmental changes resulting from power plant operations. Furthermore, benthic assemblages consist of diverse organisms with a variety of feeding modes, reproductive strategies, and physiological tolerances to environmental conditions, including temperature. Their distribution thus should be a sensitive indicator of the area of estuary bottom that is affected by operations of the Chalk Point SES. Several benthic species inhabiting the Chalk Point region are listed as RIS in Maryland thermal regulations. These include *Mya arenaria*, the soft-shell clam; *Rangia cuneata*, the brackish water clam; *Macoma balthica*, the *Macoma* clam; *Crassostrea virginica*, the American oyster; and *Callinectes sapidus*, the blue crab. These species are considered essential to the maintenance of balanced indigenous populations in the receiving water body. Any adverse effects on their populations from operations of the Chalk Point

SES therefore must be carefully evaluated to ensure that no regional or system-wide consequences will result.

B. TYPES OF POWER PLANT IMPACTS

Planktonic developmental stages and free-living benthic species are entrained into the condenser cooling system or into the thermal plume of the Chalk Point SES, where they experience thermal and mechanical stresses causing direct mortality as well as injury. In summer, when ambient water temperature is high, plant effluent increases discharge temperatures above the lethal limits of some benthic species and thus causes mortality. Thermal discharges below lethal limits impair physiological processes including reproductive timing, fecundity, reproductive success, and growth (Coutant and Talmadge, 1977). In addition, chlorine injected into condenser cooling water to control biofouling during warm seasons is acutely toxic to most benthic organisms at concentrations in the parts-per-million to parts-per-billion range.

Phytoplankton, zooplankton, and other organisms killed by entrainment and impingement are returned to the receiving body and settle to the bottom near the discharge site, thereby increasing the amount of food available for benthic organisms. Such organically enriched habitats favor certain benthic organisms (e.g., oligochaetes) at the expense of others that are preferred food of fish and crabs (Brinkhurst and Simmons, 1968; Howmiller and Scott, 1977). Oligochaetes are also intermediate hosts for a variety of parasites that adversely affect fish (e.g., Cooper et al., 1978). Thus, oligochaetes are potential nuisance organisms.

Corrosion of the copper-nickel condenser tubes releases soluble copper into the aquatic environment, where oysters and other benthic organisms can concentrate it in their tissues (Roosenburg, 1969; McIntyre, 1977; Pringle et al., 1968). High tissue burdens of copper turn the edible meat of oysters a greenish color and give it a bitter taste, making the oysters unmarketable. Furthermore, when benthic organisms containing high tissue levels of metals are eaten by predators, the metals they contain are frequently transferred through the food web and adversely affect higher trophic levels (Wolfe et al., 1982; Steele et al., 1970). Metals accumulated in oysters or predators (fish and crabs) could be transferred to man.

The relocation of large numbers of blue crabs from the intake area to the discharge canal by the screen wash and auxiliary pump return systems affects blue crab distributions in the nearfield area. In addition, dead organisms emptied into the discharge canal by the screen-wash return systems attract crabs to the canal. Blue crabs in the discharge canal or the nearfield region are exposed to elevated temperatures and chlorine residuals. Exposures that exceed the crabs' tolerances affect their distribution and physiological condition (such as growth) and cause mortality.

Adult and juvenile blue crabs entrained into the intake area of the Chalk Point SES with cooling water flows are impinged on traveling screens and entrained through unscreened auxiliary pumps. When intake screens are rotated and cleaned of debris, impinged crabs are washed into a screen-wash return trough that empties into the head of the discharge canal. During impingement and screen washing, crabs are mechanically injured (e.g., lose appendages) and some are killed. Crabs that survive the stresses of impingement encounter near-lethal temperatures and chlorine decay products in the Chalk Point discharge canal, where additional mortality results. Some adult and immature blue crabs gain access to internal plant structures, either by passing through holes between intake screens and bulkheads, or by passing over the tops of rotating screens when the water spray system fails to wash them off. Crabs that gain access to internal plant structures are killed (ANSP, 1983a). Crabs entrained through the auxiliary pumps come in contact with internal pump structures and experience mechanical damage (e.g., through losing appendages and being cut into pieces), and many die immediately (Hirshfield et al., 1982). Those surviving auxiliary pump entrainment are returned to the receiving body via the discharge canal. Delayed mortality from auxiliary pump entrainment occurs in the discharge canal and in the receiving water body.

C. SUMMARY OF SPECIFIC FINDINGS

Benthic Communities

Benthic assemblages near the Chalk Point SES are composed of a mixture of estuarine and marine species. Freshwater species are abundant only during periods of low salinity. In species composition, benthic communities in the Patuxent River are similar to those of other oligohaline-mesohaline regions of the Chesapeake Bay (Lippson et al., 1979; Holland and Hiegel, 1981; ANSP, 1983a). The four benthic assemblages found along the Patuxent's estuarine gradient are:

- A tidal freshwater community upstream of Jones Point (river kilometer 60). Freshwater species, mainly oligochaetes and chironomids, numerically dominate this community. Abundances are generally low.

- An oligohaline community between Jones Point and Holland Cliff (river kilometer 42). This community is dominated by estuarine species (i.e., Cyathura polita, Leptocheirus plumulosus, Macoma balthica, Tubificoides brownae, T. heterochaetus, and T. maureri). Abundances are low.

- A low mesohaline community in the Chalk Point region (Holland Cliff to the Benedict Bridge--river kilometers 42-35). Estuarine species (i.e., Corophium lacustre, Cyathura polita, Heteromastus filiformis, Leptocheirus plumulosus, Macoma balthica, Nereis succinea, Tubificoides brownae, T. heterochaetus, T. maureri, and an unidentified Tubulanidae) dominate this community. A few of these species (Cyathura polita and T. maureri) attain their density maxima in this region. Abundances are high compared with those in the tidal freshwater and oligohaline habitats.

- A high mesohaline community between Benedict and Solomons (river kilometers 35-10). Most species that are abundant in low mesohaline habitats are also abundant in this high mesohaline habitat. In addition, several marine species that are collected from low mesohaline habitats during low-flow periods are abundant year round in high mesohaline areas (i.e., Eteone heteropoda, Haminoea solitaria, Macoma mitchelli, Mulinia lateralis, Mya arenaria, and Streblospio benedicti). Benthic abundances are higher than in tidal freshwater and oligohaline habitats but lower than in low mesohaline habitats.

Predation is not a major factor influencing benthic stock size in the Chalk Point region (Holland and Hiegel, 1981). Furthermore, organic enrichment experiments suggest that abundances of benthic organisms, including oligochaetes, in the Patuxent are not strongly affected by the amount of organic material in bottom sediments (Holland and Hiegel, 1981). Salinity is the major factor controlling benthic abundance in the Patuxent.

Densities of several benthic species in the discharge region are higher than can be attributed to natural factors alone (ANSP, 1983a). These differences are particularly apparent after recruitment (Holland and Hiegel, 1981; ANSP, 1983a). The species with higher recruitment near the plant discharge (i.e., Heteromastus filiformis, Leptocheirus plumulosus, Macoma balthica, and Tubificoides maureri) are those that have higher abundances and more successful recruitment near sewage treatment facilities in the oligohaline/mesohaline transition zone of the Chesapeake Bay (Shaughnessy and Holland, 1984). One (H. filiformis) is heat tolerant (ANSP, 1983a).

In low-salinity years, the standing stock size of oligochaetes (Tubificoides spp.) in the thermally affected part of the Chalk Point discharge region is higher than can be attributed to natural factors (Holland and Hiegel, 1981; ANSP, 1983a). In addition, one oligochaete species (Tubificoides heterochaetus) has a fall recruitment pulse in the discharge region that is lacking at reference areas (Holland and Hiegel, 1981). The timing of recruitment for other dominant benthic species does not differ between the thermally affected and reference areas (Holland and Hiegel, 1981; ANSP, 1983a). Because estuarine oligochaetes are very small, their high abundance in the discharge area does not significantly increase total macrobenthic biomass above that at reference areas.

Chalk Point discharge canal sediments are not toxic or uninhabitable for benthic biota (Holland and Hiegel, 1981). Relatively few macrobenthic species, however, inhabit the Chalk Point discharge canal during summer at partial generating loads. Field experiments suggest that high canal temperature is the primary factor in the reduced abundances in the canal. Chlorine residuals may, however, also be a contributing factor (Holland and Hiegel, 1981; ANSP, 1983a). Heat-tolerant benthic species (Heteromastus filiformis and Nereis succinea) are more abundant in and around the terminus of the discharge canal than can be attributed to natural conditions alone (ANSP, 1983a).

The total number of benthic species present at the discharge site during partial-power operations is the same as that at reference stations. In low-salinity years, however, the extremely high oligochaete abundance in the discharge area lowers the diversity of the benthic community in that area (Holland and Hiegel, 1981; ANSP, 1983a).

The RIS clam, Macoma balthica, consistently constitutes over 90% of the benthic-biomass standing stock in the Chalk Point region. During partial-power operations, the growth rate of M. balthica is higher and the mortality rate lower near the Chalk Point SES than in other regions of the Patuxent. However, because similar patterns for growth and mortality of M. balthica were observed before the Chalk Point SES was constructed, these differences cannot be attributed to plant operations (McErlean, 1964; Holland and Hiegel, 1981). As for other benthic species, salinity is the primary factor determining the spatial distribution and population characteristics of M. balthica (McErlean, 1964; Holland and Hiegel, 1981; ANSP, 1983a). Full-power operations may deplete M. balthica populations because absolute bottom temperatures over part of the discharge region are likely to exceed thermal tolerances of adults and juveniles (>32-33°C) (Kennedy and Mihursky, 1971). The size of this region is unknown, but it is suspected to be greater than 40 ha. Unfortunately, no accurate projections of nearfield bottom temperature are available for full-power operations.

Amphipods (Corophium lacustre) and opossum shrimp (Neomysis americana) are abundant in the intake area and thus are susceptible to high entrainment losses (ANSP, 1983a). Other free-living benthic species are not particularly abundant in the intake region. Populations of Neomysis consistently decline from intake to discharge; entrainment mortality varies from a few percent to over 90%, but was generally in the 50-70% range (ANSP, 1983a). In contrast, Corophium is occasionally more abundant in discharge samples than in intake samples (ANSP, 1983a). This finding is not surprising, since this fouling organism builds tubes on intake, internal plant, and auxiliary pump structures as well as on the riprap in the discharge canal. Submerged-substrate studies indicated that Corophium productivity was consistently higher in thermal discharges at Chalk Point than in ambient conditions (ANSP, 1983a; Cory and Nauman, 1968). Thus, the increased abundances of Corophium in the discharge canal are probably related to the overall higher abundances of this species in thermally affected areas. Entrainment losses of free-living benthic organisms have little influence on nearfield population levels of these biota. Free-living benthic species (i.e., amphipods, grass shrimp, and opossum shrimp), however, have high mortalities (38%, 60%, and 100%, respectively) after exposure in the laboratory to chlorine concentrations and temperatures that mimic summer entrainment stresses (chlorine concentrations, 0.15 to 0.30 ppm; ΔT, 2-10°C; acclimation temperature, 21-27°C) (ANSP, 1983a).

Oysters

The Chalk Point SES is located near the upper limit of the oyster's natural salinity range in the Patuxent River, and there are no oyster bars in the discharge area or upstream of the power plant site (ANSP, 1983a). Thus, the poor growth of oysters near the Chalk Point SES is mostly a result of stressful salinity regimes and is unrelated to plant operations (Roosenburg, 1968, 1969; ANSP, 1983a, 1983b). Patuxent oyster populations experienced high mortalities in the spring and summer of 1972 from low salinities caused by Tropical Storm Agnes (Abbe and Hart, 1974). Salinities remained below average for several years after Agnes, and oyster recruitment and productivity in the vicinity of Benedict have not yet recovered from this stress (ANSP, 1983a).

The commercial oyster beds (private and public) closest to the Chalk Point SES are located several kilometers downstream of the discharge-canal terminus and are exposed to only small amounts of excess heat (ΔT < 1°C--ANSP, 1983a). One small noncommercial oyster bar (Farmers Bar) is close enough to the plant's discharge to experience more than 2°C excess heat (Roosenburg, 1968, 1969; ANSP, 1983a). Water temperature at Farmers Bar, however, does not exceed the thermal tolerance of oysters (~36°C for prolonged exposure--Galtsoff, 1964; Tinsman and Maurer, 1974).

The physiological condition (i.e., health) of oysters varies seasonally with reproductive state and is poorest in summer, after gonad development. The condition of tray-held oysters near the Chalk Point SES was similar to that at reference areas and was not influenced by plant operations (Roosenburg, 1968, 1969; ANSP, 1983a, 1983b).

The composition of the benthic fauna attached to oysters near the Chalk Point SES differs from that at downstream reference areas. The differences, however, are related to the natural salinity gradient and not to operations of the Chalk Point SES (ANSP, 1983a).

Copper released from corrosion of the copper-nickel condenser tubes of the Chalk Point SES is bioconcentrated by oysters upstream of Benedict (ANSP, 1983a, 1983b; Roosenburg, 1968, 1969). This bioaccumulation is an indicator that plant-related copper contamination is occurring in the nearfield area. The affected region is not prime oyster habitat, however, and oysters are not commercially harvested there. High tissue burdens of copper have rarely been reported in oysters from commercial beds in the Patuxent River which are mainly located downstream of the Chalk Point SES (ANSP, 1983a, 1983b; Roosenburg, 1968, 1969). Bioconcentration of copper does not reduce survival of oysters near the Chalk Point SES (ANSP, 1983a, 1983b). In fact, mortality was lower for tray-held oysters in the discharge canal, which have high tissue burdens of copper and are exposed to near-lethal temperatures, than for oysters held in either the intake canal or the nearfield area (ANSP, 1983b).

No surveys have been conducted to assess whether copper released from corrosion of the condenser tubes at the Chalk Point SES is accumulated by benthic biota other than oysters. Dominant fish species in the Patuxent generally feed on benthic organisms in proportion to their abundance, however, and metal levels in tissues of these bottom-feeding fish are no higher near the plant site than in other regions of the Patuxent River or in other tributaries of the Chesapeake Bay. If the benthos do accumulate copper or other metals from plant operations, the available evidence is that they do not pass these metals up the food web in quantities leading to bioconcentration in fish populations (Homer et al., 1980; ANSP, 1983a). Most fishes in the in the Patuxent are mobile, so it seems unlikely that localized accumulation of metals in benthos would result in significant increases in metal levels in fish tissues. The only fish species that has limited movement and feeds heavily on benthic organisms is the mummichog; metal levels in mummichog tissues have not been determined.

Zinc levels in oysters are consistently higher near the Chalk Point SES than at downstream reference areas. Cadmium concentrations are high in oysters throughout the Patuxent River. The specific source(s) of zinc and cadmium are unknown, but do not appear to be related to operations of the Chalk Point SES (ANSP, 1983a). Rather, they are probably related to long-term trends in metal inputs and to the pollution history of the Patuxent (U.S. EPA, 1983).

Blue Crabs

Blue crabs inhabit various parts of the Chesapeake Bay during their life cycle. They mate throughout the Bay and its tributaries (Churchill, 1919; Truitt, 1939; van Engel, 1958). To spawn, females migrate to the mouth of the Bay and to adjacent coastal areas. Early development takes place in these spawning areas, so planktonic life stages of blue crabs are not found in the Patuxent River and are not entrained by the Chalk Point SES. The Chalk Point region is, however, a nursery area for juvenile crabs (ANSP, 1983a; Souza et al., 1980). Juveniles less than 9.5 mm in carapace width are entrained through the traveling screens that protect intake structures and enter the cooling system, where they are killed. No estimates have been made for blue crab entrainment at Chalk Point. The figure is probably low, however, because crabs in the Patuxent are small enough to be entrainable for only 1-2 weeks. It should be pointed out that plant entrainment is separate from auxiliary pump entrainment, which will be discussed later.

Blue crabs are abundant near the Chalk Point SES between June and October, and abundances peak in July and August. Abundances are lowest in winter and early spring, when the crabs are inactive and buried in sediments (ANSP, 1983a; PEPCO, 1980, 1981, 1982). Population estimates indicate that the Patuxent estuary supports 3-4 million to as many 70 million crabs (Souza et al., 1980). Many (~10-15%) these crabs are concentrated in the Chalk Point region, especially the intake area (Souza et al., 1980). Their preferred habitat is the shallow nearshore areas (ANSP, 1983a; PEPCO, 1980, 1981, 1982; Souza et al., 1980; Homer et al., 1979a).

In summer, blue crabs are more abundant in the Chalk Point discharge canal than in the adjacent parts of the estuary, probably at least partly because of the large numbers of crabs that are relocated to the discharge canal after impingement and auxiliary pump entrainment (Homer et al., 1979a). In addition, crabs may be attracted to the discharge canal to feed on fish and crabs killed by auxiliary pump entrainment or impingement and discharged to the canal.

At partial-power operations, thermal discharges from the Chalk Point SES do not adversely affect the distribution, physiological condition, or size of blue crabs in the Patuxent River, and no adverse effects are projected for full-power operations (ANSP, 1983a; Souza et al., 1980; Holland and Johnson, 1981). Depending upon the season, crabs are attracted to or avoid the thermal plume, but the plume does not block their natural migrations. Salinity is the major factor controlling blue crab abundance and distribution in the Patuxent (Holland and Johnson, 1981). The sex ratio and average size patterns of blue crabs also vary along the Patuxent River in response to salinity distribution.

The annual impingement rate in 1976 and 1977, before installation of the barrier net, was between 1.6 and 2.2 million for blue crabs (average=1,948,132). Assuming an impingement mortality rate of 14.3%, the estimated dollar value of this impingement is $94,710 (ANSP, 1983a). The annual impingement rate after the barrier net was in place (1982-1983) is estimated to be 380,760 crabs, a reduction of 80% below the pre-barrier net figure. The upper and lower 95% confidence limits for this impingement estimate are 298,264 and 463,256 (PEPCO, 1983b). The estimated dollar value of the reduced impingement is $5,378. Although these figures suggest that the barrier net is quite effective in reducing impingement, it must be remembered that this conclusion is based on data for only 1 year.

Blue crab impingement rates are similar for Units 1 and 2, and are not related either to the amount of food (finfish) impinged on intake screens or to screen location (Hixson, 1980; PEPCO, 1983b). Rather, crab impingement is proportional to crab abundance in the nearfield area. Impingement is highest in warm seasons and lowest in cold seasons (PEPCO, 1983b). Crabs that survive impingement are relocated to the discharge canal, and typically are not subsequently reimpinged (Souza et al., 1980). Impingement mortality is greater for intermittent screen operations than for continuous screen operations (ANSP, 1983a).

Post-impingement mortality of blue crabs at the Chalk Point SES is 10-15% as long as chlorine levels in the discharge are less than 0.1 ppm and temperature is lower than 35°C (ANSP, 1983a). Crab mortality is high, however, after short exposures to temperatures above 37°C, especially if the chlorine concentration is greater than 0.2 ppm (ANSP, 1983a; PEPCO, 1983b). In the discharge canal, mortality averages 31% when canal temperatures exceed 37°C (PEPCO, 1983b) as they did on 12 days between 1981 and 1983, during partial-power operations. Temperatures are projected to exceed 37°C more frequently (>30 days/yr) during full-power operations.

Auxiliary pump entrainment of blue crabs at Chalk Point, estimated to exceed 1 million crabs annually before installation of the barrier net, was approximately equal to impingement (Hirshfield et al., 1982). This entrainment was reduced by 95-99% following installation of the barrier net (PEPCO, 1983a). The reductions in impingement and auxiliary pump entrainment after installation of the barrier net are substantial; as mentioned above, however, the conclusion that the net is effective is based on data for only 1 year. The number of crabs entangled in the barrier net is only a few percent of the number impinged or entrained through auxiliary pumps (PEPCO, 1983b). The immediate mortality rate of crabs entrained through auxiliary pumps is about 42% (range, 40.3-52.7%--Hirshfield et al., 1982).

Mean width is greater for impinged blue crabs than for crabs entrained through auxiliary pumps (112 mm vs 101 mm) (Hirshfield et al., 1982). With a barrier net, auxiliary pump entrainment exceeds impingement, because the barrier net is not entirely effective against the smaller crabs, which are most vulnerable to auxiliary pump entrainment (PEPCO, 1983a). Auxiliary pump entrainment is expected to increase at full-load operations, when the auxiliary pumps will be used more frequently.

The above information was used to estimate blue crab population losses due to impingement alone and losses due to impingement plus auxiliary pump entrainment. Annual losses when auxiliary pumps are operating exceed losses when the pumps are not operating by a factor of about two (35,884 vs 77,978). Even if discharge canal temperatures are higher than 37°C for 30 days and discharge-canal mortality rates are 100%, crab losses are lower without auxiliary pumps than with them (37,978 vs 64,375). The use of auxiliary pumps increases annual blue crab losses apparently because many crabs entrained through these pumps are killed instantly. The continued use of auxiliary pumps should thus be carefully evaluated and probably discontinued as a technology to protect blue crabs.

Nuisance Species

The community of fouling organisms at Chalk Point is dominated by the soft-bodied bryozoan *Victorella pavida*, the hydroid *Bimeria franciscana*, and the tube-building amphipod *Corophium lacustrea* (ANSP, 1983a; Weisberg et al., 1984a). However, the barnacle *Balanus improvisus*, the tunicate *Molgula manhattensis*, and the anemone *Sagartia leucolena* were abundant historically, particularly in high-salinity years (ANSP, 1983a). These organisms are potential nuisance species, since they foul boat bottoms and fishermen's nets as well as power plant structures. The abundance of fouling organisms is greatest between May and September, peaking in July and August (ANSP, 1983a;

Weisberg et al., 1984a). Densities of fouling biota vary from year to year and station to station. Operations of the Chalk Point SES enhance the growth and productivity of fouling organisms in the discharge canal during spring and depress it there during summer. The summer growth depression is probably related to the synergistic effects of chlorine and high ambient temperature. In the nearfield area just downstream of the discharge canal terminus, plant operations stimulate the growth of fouling organisms in all seasons (ANSP, 1983a). No regional effects on the growth of fouling organisms have been observed.

Nematode parasitism of the fish *Fundulus heteroclitus* is higher in the discharge region than in the intake area during low-salinity years, when oligochaetes are abundant in the discharge region (Hirshfield et al., 1983), but not during high-salinity years, when oligochaete abundances in the discharge canal are reduced (Weisberg et al., 1984b). *Eustrongylides* parasitism does not appear to impair the physiological condition of mummichogs under laboratory conditions, and no consistent adverse physiological effects were found from *Eustrongylides* parasitism in a bay-wide study (Weisberg et al., 1984b). In the Chalk Point discharge region, however, infected fish weighed 5% less than uninfected fish of the same length, and the ovaries of infected females weighed 50% less than those of uninfected females of the same length (Hirshfield et al., 1983). The adverse effects of *Eustrongylides* parasitism at Chalk Point may be due to a synergistic interaction between plant-related stresses and parasitism. Although *Eustrongylides* has been reported to parasitize commercially and recreationally important fish stocks, the rate of *Eustrongylides* parasitism in these other species in the Patuxent has not been rigorously determined (Weisberg et al., 1984; Hirshfield et al., 1983). Thus, although power plant operations at Chalk Point increase the prevalence of a nuisance parasite, this increased prevalence has no known long-term consequences.

The Chalk Point SES releases a small amount of chlorine-treated sewage (about 12 m^3/min) into the discharge canal. There are no indications, however, that these discharges increase fecal coliform counts (Otto, 1983). Bacterial standing stocks, as indicated by ATP levels in sediments, and bacterial production, as indicated by incubation experiments, are no higher in the discharge region than at upstream or downstream reference areas (ANSP, 1983a; Holland and Hiegel, 1981).

D. SIGNIFICANCE OF FINDINGS AND CONCLUSIONS

Although the abundance (i.e., biological productivity) and the functional properties (metabolism and nutrient flux--see Chapter II) of the benthos differed significantly between thermally affected areas and reference areas at partial-power operations of the Chalk Point SES, these differences did not adversely effect the Patuxent ecosystem. At full-power operation, heat-tolerant species, now abundant only near the discharge canal, will become more abundant in the nearfield area. This enhancement, however, is not likely to displace preferred benthic species or to disrupt food-web relationships.

During summertime full-power operations, discharge temperatures over a small part of the discharge region (about 40 ha) will exceed the lethal limit of some benthic organisms, particularly the RIS clam Macoma balthica (Kennedy and Mihursky, 1971). It is likely that these discharges will reduce M. balthica populations in the immediate discharge region, thereby adversely affecting the successful completion of the clam's life cycle in a limited part of its range. Since M. balthica constitutes more than 90% of the benthic biomass in the middle reaches of the Patuxent and is a major food-web link in the nearfield ecsystem, biomass losses from reductions in M. balthica populations may be propagated through the local food web. Replacement of M. balthica's biomass or food-web position by heat-tolerant species that are preferred prey of fish and crabs seems unlikely. The area from which M. balthica will be excluded, however, is likely to be small, so no regional consequences are projected.

The part of the Patuxent estuary adjacent to the Chalk Point SES is a nursery area for juvenile blue crabs, and large numbers of juveniles were impinged on intake screens or entrained through the auxiliary pumps before a barrier net was installed across the entrance to the intake canal. The barrier net has been shown, based on 1 year of study, to be capable of reducing impingement and auxiliary pump entrainment by more than 80%. With a barrier net in place, impingement is probably not a serious threat to blue crab populations in the Patuxent estuary, and losses due to auxiliary pump entrainment exceed losses due to impingement. Auxiliary pump entrainment of crabs could be reduced further by using the existing barrier net more efficiently (e.g., by ensuring that the bottom of the net is secured to the bottom of the intake canal; by installing an additional, smaller-mesh barrier net on the intake side of the existing net; or both). Use of the existing barrier net should be considered as an operating permit requirement for the Chalk Point SES, and technologies that might optimize its performance should be evaluated.

Operation of auxiliary pumps increases, rather than decreases, impingement- and entrainment-related mortality of blue crabs. The reduction in thermal stress provided by use of these pumps is thus of little benefit to crab populations. The use of auxiliary pumps as a technology for protecting blue crabs is counterproductive.

In summer, the benthic fauna inside the discharge canal are adversely affected by high temperatures and plant effluents (e.g., chlorine). The discharge canal, however, is within the plant's allowable mixing zone. During full power generation, bottom water temperatures like those in the discharge canal at partial power generation are projected to occur over at least 40 ha of the nearfield area. Full-power operations will thus have thermal effects in the nearfield area outside the allowable mixing zone. The affected sites, however, will be limited to the nearfield area and are not regional in scope. Copper bioaccumulation by oysters is an indicator that plant-related copper contamination is also occurring in the nearfield area.

The high abundances of oligochaetes observed in the discharge region in low-salinity years do not appear to constitute an adverse plant-related enhancement of a nuisance organism. The high nearfield standing stocks of oligochaetes do not affect the abundances of other benthic species, the sediment oxygen demand, or the fluxes of nutrients from sediments. Benthic prey for bottom-feeding fish are at least as numerous in the discharge area as in other regions of the Patuxent River. In years when oligochaetes are abundant in the discharge region, the rate at which *Eustrongylides* (a nematode parasite of fishes and birds, with intermediate stages in oligochaetes) parasitizes *Fundulus heteroclitus*, a shore-zone RIS fish, is higher in the discharge area than in the intake region. The high rate of parasitism, however, does not adversely affect fish populations in the region.

The plant-related enhancement of fouling organism populations in the discharge region is of minor consequence to boat users, and does not constitute enhancement of a nuisance organism. There are no permanent boat moorings or marinas in the affected region. The enhanced growth of fouling organisms on plant intake structures, however, attracts fish and crabs and keeps them in a location where they are at high risk of entrainment, impingement, or both.

Table V-1. Fish and crab impingement and entrainment mortalities at Chalk Point with and without operation of auxiliary pumps.

Species	Impingement		Entrainment		Mortality estimate with pumps on		Mortality estimate with pumps off	
	Number of fish or crabs (Jul-Sep)	Mortality (%)	Number of fish or crabs	Mortality (%)	Number dead (Jul-Sep)	Dollar value lost	Number dead (Jul-Sep)	Dollar value lost
Atlantic menhaden	127,832	53.0	127,629	95.2	208,684	30,008	86,690	10,186
Spot	17,824	36.0	37,286	91.0	44,680	10,728	10,013	1,118
White perch	11,722	3.0	76,773	69.7	63,965	21,804	3,936	519
Blue crab	127,304	10.0	80,307	41.8	77,978-87,573	11,738-13,139	35,884-46,106	5,567-6,510

ASSUMPTIONS

- All fish and blue crabs enter the discharge canal via entrainment or impingement.
- Delayed mortality due to entrainment or impingement is insignificant.
- The operation of auxiliary pumps does not affect the number of fish and crabs impinged on the traveling screens.
- Mortality due to thermal effects is independent of fish size.
- Discontinuous mortality functions were used. If continuous mortality functions are used, the difference between the two conditions may decrease by up to 10%.
- The critical thermal maximum (CTM) for blue crabs is 37°C. The CTM for Atlantic menhaden, spot, and white perch is 35°C.

DATA SOURCES

1. PEPCO (1984)
2. PEPCO (1983)
3. Coutant (1977)

FORMULAS FOR MORTALITY ESTIMATES

- Auxiliary pumps off

$A \cdot C + A-(A \cdot C)\ F_1\ E_{T_1} + A-(A \cdot C)\ F_2\ E_{T_2} = M_1$

- Auxiliary Pumps On

$A \cdot C + A-(A \cdot C)\ F_1\ E_{T_1} + A-(A \cdot C)\ F_2\ E_{T_2} + B \cdot D + B-(B \cdot D)\ F_1\ E_{T_1} +$

$+ B-(B \cdot D)\ F_2\ E_{T_2} = M_2$

M_1 = Mortality with pumps off
M_2 = Mortality with pumps on
A = Numbers impinged
B = Numbers entrained
C = Impingement mortality rate
D = Entrainment mortality rate
E_{T_1} = Thermal mortality below CTM

E_{T_2} = Thermal mortality above CTM

F_1 = Proportion of days discharge temperature is below CTM
F_2 = Proportion of days discharge temperature is above CTM

VI. FINFISH

A. INTRODUCTION

Of the biota affected by the operations of the Chalk Point SES, the finfishes may be the ones for which the public and regulatory agencies show the most concern. Although this concern results primarily from the commercial and recreational value of fisheries resources, finfishes also have important structural and functional roles in estuarine ecosystems. For example, planktivorous species (e.g., anchovy, menhaden) and early life stages (e.g., ichthyoplankton) of finfishes feed on phytoplankton and zooplankton. These plankton-feeding fishes in turn are eaten by predatory game fish, such as striped bass. Predatory fishes hold a position near the top of the estuarine food web, and the success and survival of their populations are often indirectly influenced by changes in the ecosystem, anthropogenic or natural, or both. Plant-related losses to planktivorous species thus represent potential adverse impacts to key links in the food web and are indicators of long-term system-wide responses. This is the basis for including forage species as RIS in state regulations governing thermal discharges. Plant-related losses to predatory fish generally represent losses to commercial and recreational fisheries and also indicate long-term system-wide responses.

The relative abundance, species composition, and life stages of the Patuxent's fish community vary with season and with environmental conditions (e.g., salinity, temperature, depth). The Chalk Point region serves as a spawning habitat, nursery area, and/or feeding grounds for many species (Mihursky and Boynton, 1978). Striped bass spawn upstream of the Chalk Point SES, and during rare periods of extremely high freshwater inflows, their larvae may be found near plant intake and discharge structures (Mihursky et al., 1980). White perch are abundant throughout the Patuxent River, particularly in less saline habitats (Mansueti, 1961).

B. TYPES OF POWER PLANT IMPACTS

Two types of interactions with power plant structures, impingement and entrainment, cause immediate mortality or physiological and morphological injury to fishes in various life stages. Adult and juvenile fishes are impinged on the traveling screens protecting circulating pumps, or entrained into auxiliary cooling pumps. Small fishes (e.g., bay anchovy) and planktonic fish eggs and larvae are entrained into the condensers, through the auxiliary pumps, or in the thermal plume, where they are exposed to elevated temperatures, mechanical stress, and in warm months, chlorine.

Entrained and impinged fish are returned to the receiving water body through the discharge canal, where they are exposed to near lethal-temperatures and chlorine decay products during certain times at the year. These stresses may increase the susceptibility of entrained or impinged fish to disease, parasitism, or predation. Plant discharges may block migratory routes preventing fish from reaching normal spawning and nursery areas. In addition, depending on season, fish may seek or avoid the discharge area. During winter, if the plant shuts down and temperatures in the discharge area suddenly decline, some fish may be killed by the rapidly declining temperatures. Attraction to or avoidance of the discharge area could also adversely affect growth rates and physiological condition of fish populations.

C. SUMMARY OF SPECIFIC FINDINGS

Impacts on Early Life Stage of RIS

Cooling-water entrainment (plant and plume) from the Chalk Point SES is unlikely to have much direct effect on regional ichthyoplankton stocks of freshwater and anadromous fishes (yellow perch, species of Cyprinidae, striped bass, white perch, species of Clupiidae), because their spawning and nursery habitats are upstream of the zone of plant influence (Mihursky et al., 1980; ANSP, 1983a). Only during rare periods of extremely high freshwater inflow are eggs and larvae of these species transported into the vicinity of the plant intakes and discharges (Mihursky et al., 1980; ANSP, 1983a). Ichthyoplankton of estuarine species (bay anchovy, naked goby, and silversides), however, are concentrated near plant intake and discharge structures and thus are vulnerable to large entrainment losses.

The Maryland Power Plant Siting Program has developed a linearized modeling procedure for estimating the potential impacts of power plant operations on early life stages of RIS at the population, regional economic, and regional ecological levels (Polgar et al., 1979, 1981). The procedure bridges two traditional methods of computing impact in that empirical field data are used in the framework of several mathematically simple (e.g., linear) conceptual submodels. The potential entrainment loss of adults is estimated from losses of early life stages under the assumptions that entrainment mortality is 100%, and planktonic life stages behave as passive particles. The losses of each life stage are additionally evaluated as consequent changes in the productivity of the Patuxent ecosystem and in the potential value of the estuary's fisheries. The general model assumes complete compensation for all entrainment losses of phytoplankton and zooplankton, but no compensation for losses to finfish or shellfish populations. The general model has been used successfully at many power plants throughout Maryland to project impacts on spawning and nursery areas of RIS (e.g., see Martin Marietta Corporation, 1980, 1981, 1982; Summers and Jacobs, 1981). The discussions below detail the application of the model at the Chalk Point SES.

Linearized estimates of entrainment losses to fish and shellfish populations and their associated ecological and economic impacts provide directly interpretable results only when the losses are relatively small (i.e., <10% of regional larval abundance). The reason for this limitation is that both ecological and economic impact estimates are predicated on the assumption that the system's trophic web undergoes no structural or functional changes as a result of entrainment losses (see Summers and Polgar, 1982, for a detailed discussion). This assumption may not be reasonable if entrainment losses exceed 10%. The model is thus a first-order screening procedure for determining which populations of RIS, if any, are likely to experience significant losses through entrainment of early life stages; it is not intended to provide a precise estimate of entrainment losses and their subsequent impacts.

Application of the above linear procedure at the Chalk Point SES indicates that cooling-water entrainment losses to populations of forage fishes RIS (i.e., bay anchovy, silversides, naked goby) and hogchokers are high (i.e., in the 20%-50% range). Estimation by the same procedure indicates that losses to populations of recreationally and commercially important species, however, are negligible (<3%), with direct economic losses of less than $3,000 to the Patuxent's commercial fisheries. In contrast, the potential loss of ecosystem net productivity as "unutilized" energy flow is 8%, the highest value for unutilized ecosystem productivity at a Maryland power plant that has been calculated by use of this procedure.

The estimates of 20%-50% population losses for forage species are beyond the valid range of estimation for a model based on linearization of the life-stage recruitment process. Thus, while such results serve to demonstrate clearly that entrainment losses (as well as subsequent ecological consequences) at the Chalk Point SES are potentially serious, the estimate is not precise. As a result, a need was recognized for detailed models to project the effects of plant operations on forage fish populations. Results of these detailed models estimate the magnitude of entrainment losses to spawning and nursery areas, and thus provide information useful for evaluating the potential for entrainment to have long-term system-level responses. Construcstruction of such models requires knowledge of the distributional and life cycle patterns of the forage species, summarized below.

- Bay anchovies spawn downstream of the Chalk Point SES. After hatching, larval anchovies move upstream into less saline nursery areas near the Chalk Point SES, where relatively large numbers are at risk to plant and plume entrainment (Mihursky et al., 1980; ANSP, 1983a; Loos, 1983). The last larval stage (postfinfold) is concentrated near plant intake and discharge structures. The consistently lower abundances of anchovy ichthyoplankton in the nearfield area than at reference areas suggests a potential plant effect on this species. Anchovy ichthyoplankton abundance was always lowest at the discharge canal terminus. However, because natural variation in abundance of these organisms is large (i.e., their distribution is patchy), the differences were not statistically significant (ANSP, 1983a; Loos, 1983).

- Naked goby spawns in the Chalk Point region. Goby eggs are attached to submerged objects (Lippson et al., 1979) and were not sampled in Chalk Point study programs (Shenker et al., 1983; Loos, 1983). After hatching, goby larvae move upstream; the highest densities generally were found upstream of Chalk Point (ANSP, 1983a; Shenker et al., 1983). The consistently lower abundance of naked goby ichthyoplankton near the end of the discharge canal and in the immediate nearfield region than at upstream or downstream reference areas suggests a plant effect on this species (ANSP, 1983a). However, because of the large spatial variations characteristic of these ichthyoplankton, nearfield depressions in abundance were not statistically significant (ANSP, 1983a; Loos, 1983).

- The spawning and nursery areas of silversides are in low-salinity habitats above Benedict (Mihursky et al., 1980). Silversides eggs are attached to submerged objects (Lippson et al., 1979) and were not sampled at Chalk Point (Loos, 1983). Silversides larvae are usually found within a few centimeters of the water surface. In the field programs conducted at Chalk Point, larval silverside have been sampled very poorly because of their unique distributional patterns (i.e., predominately inhabit waters very near the air-water interface). In addition, at least three species of silversides occur in the Chalk Point region (Lippson et al., 1979); larval silversides were not identified to species by Chalk Point ichthyoplankton sampling programs. The data obtained do, however, suggest some general trends. Larval densities